Sea-level Rise and Storm Effects on CoastsUnder Changing Global Climate

Plenary talk- Preparing for Sea Level Rise:

Development of an Adaptation Strategy for Delaware

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The Coastal Crisis....

Outline

- Physical processes of coastal change
 - geologic framework
 past sea-level change
 effects of tropical and extratropical storms and humans
 coastal hazard risk and vulnerability
- Global climate change, summary of climate science
 - climate warming, melting of ice sheets and glaciers, ocean expansion accelerating sea-level rise increase in storm activity, extreme weather events coastal erosion and wetland loss increase in frequency and magnitude of flooding thresholds and tipping points of coastal landforms coastal vulnerability to sea-level rise and storms
- Climate Change Science Program Report SAP 4.1

"Coastal Elevation and Sensitivity to Sea-level Rise: A Focus on the mid-Atlantic Region"



Primary Processes Driving Coastal Change

- Geologic framework and character
- Coastal plain geomorphology and gradient/slope
- Relative sea-level change global change land subsidence & uplift
- Storm events
 - tropical storms/ hurricanes extratropical storms
 - nor'easters
 - cold fronts

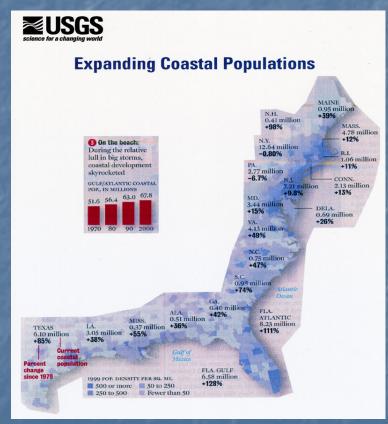
- Routine coastal processes waves, tidal currents & winds
- Sediment budgets sediment sources (headlands, cliffs) sediment sinks (washover, inlets)
- Human activities
 - coastal engineering structures dredging channels, inlets, canals
 - river modification (dams, levees)
 - fluid (oil-gas-water) extraction climate change (SLR, storms)



America's Coastal Crisis – Coastal population and development are increasingly vulnerable to coastal hazards

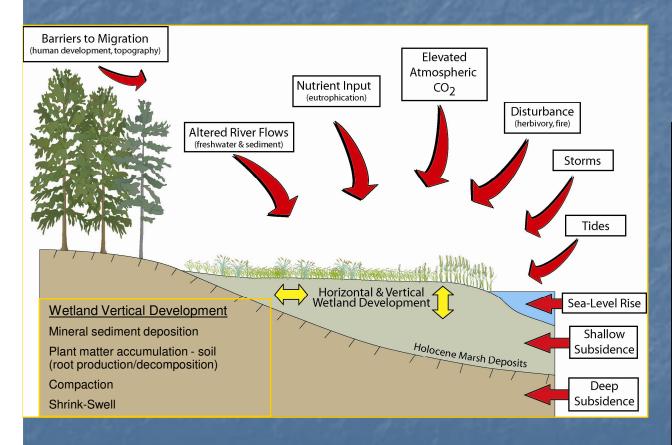


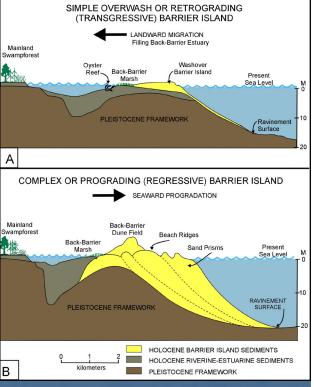
- Erosion affects all 30 coastal states
- 60-80% of coast is eroding
- DE erosion is ~ 1m (2-4 ft) annually



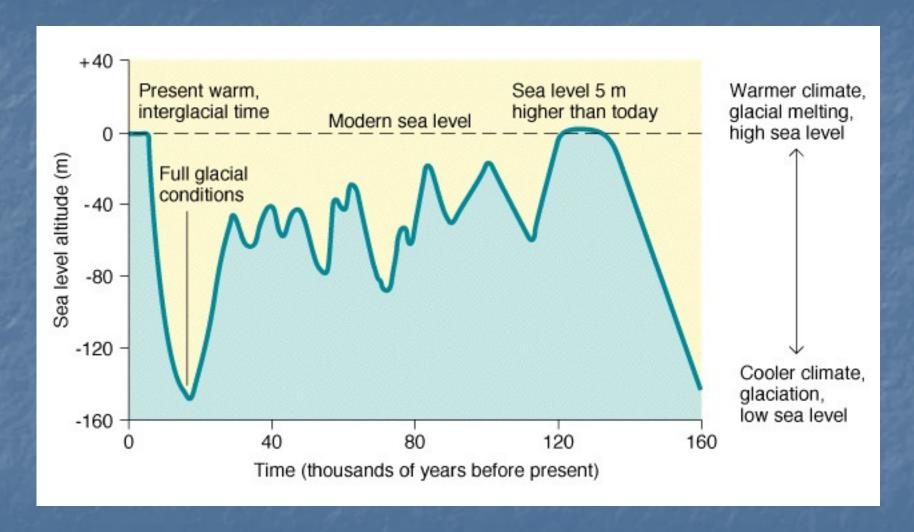
- Coastal populations have doubled
- 50% live near coasts
- Infrastructure about \$3 trillion

Coastal landforms and wetlands respond dynamically to environmental processes

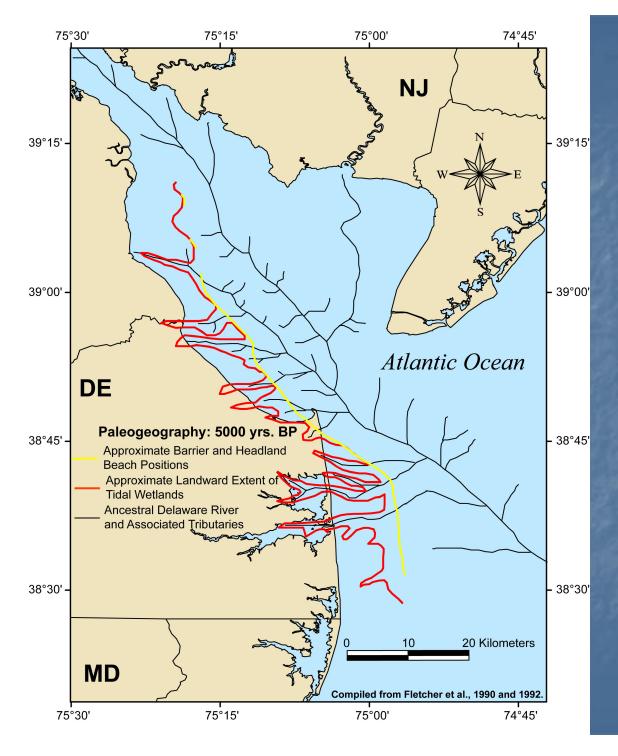




Global sea-level change over the past 160,000 years



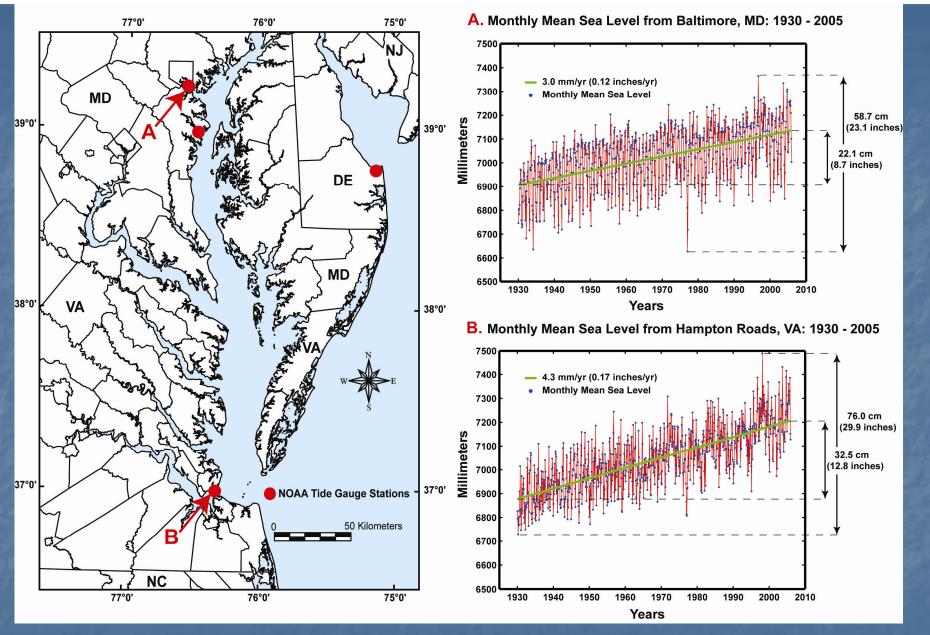
- Sea level highly variable due to natural processes
- Sea level -120 m (400 ft) lower and +4-6 m (20 ft) higher than present



Reconstruction of the Delaware coast 5,000 yrs ago based on geologic studies

- Coast was 10 km seaward
- Sea level was ~ 5 m lower
- Delaware Bay was smaller estuary
- Tidal wetlands were smaller

Based on studies by Chris Kraft, C. Fletcher and a host of Un. Delaware students



- Historical relative sea-level rise, 1930-2005, based on tide gauge records
- Relative sea-level rise from Lewes gauge is 3.2 mm/yr (1 ft per century)

Scientific Consensus

The National Academy of Sciences (2005)

"The scientific understanding of climate change is now sufficiently clear...(we urge) prompt action to reduce the causes of climate change."

National Security and the Threat of Climate Change CNA Corp (2007) for Dept of Defense

"The nature and pace of climate change are grave and pose grave implications for U.S. national security."

Intergovernmental Panel on Climate Change (2007)

"Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely (90%) ... "unequivocally" due to the observed increase in anthropogenic greenhouse gas concentrations."

U. S. Climate Change Science Program, SAP 4.1 (2009)

"Climate warming will raise sea levels and potentially increase storms, resulting in increased erosion, wetland loss, salt water intrusion. Actions and plans are needed at national and state levels for adaptation to future climate conditions."

SAP 4.1: Sea-level rise (SLR) is accelerating Primary climate change impacts on coasts are SLR and increased

- major storm intensity
- In the past 400,000 years, sea level has been 120 m lower and 5 m higher than present, but rising at variable rates for the past 20,000 years
- Data over the past 15 years show SLR appears to be accelerating
- Relative SLR for some coastal regions in the U.S. such as the mid-Atlantic and Gulf of Mexico is greater than the global average due to land subsidence
- Climate model studies suggest SLR rates in the 21st century will exceed rates over the past century. Rates could be much greater if ice losses in Greenland and Antarctica increase

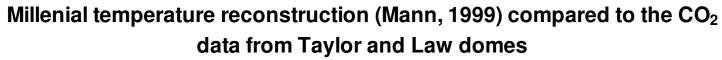
In SAP 4.1, no new SLR projections were developed. Three scenarios broadly representing the range in the literature were

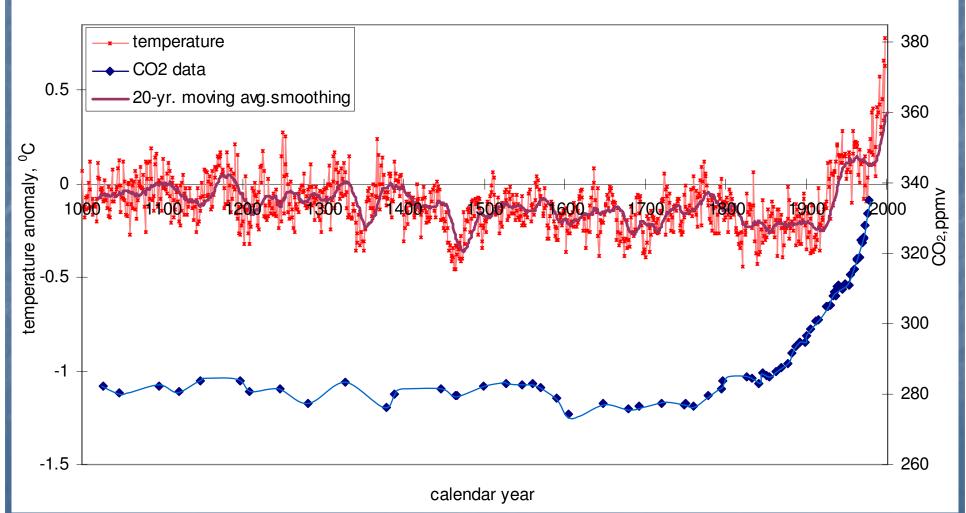
Need for Adaptation for Sea-level Rise

"There is no longer any question that we are in the midst of an unprecedented era of rapid climate change. Now we need to understand what lies ahead and what we can do in response—both to adapt to a warmer world and to prevent things from getting worse"

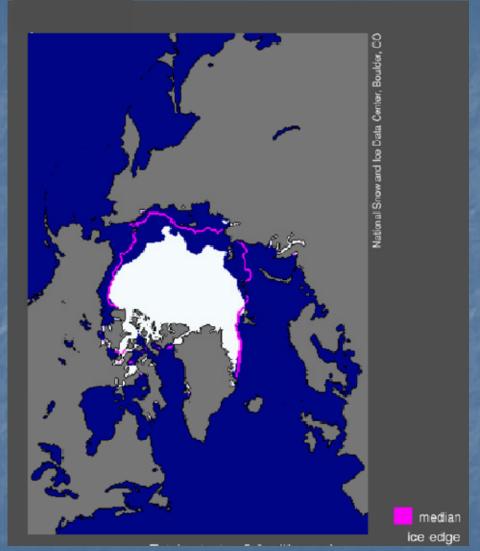
National Science Foundation & Discover: "The Challenges of Climate Change" event, 2 March 2009, San Francisco, CA

Global temperature and CO2 record for the past 1,000 yrs based on tree ring and Antarctic ice core analyses





Arctic summer sea ice is rapidly disappearing... 2009?



ice edge

September 2005

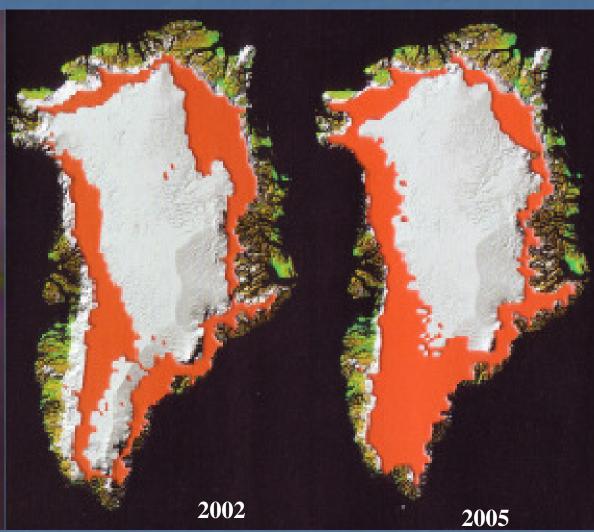
September 2007

US National Snow & Ice Data Center, 2007

Greenland ice sheet melting is accelerating......



In 1992, scientists measured the amount of melting in Greenland as indicated by red areas



Ten years later, in 2002, the melting was much greater

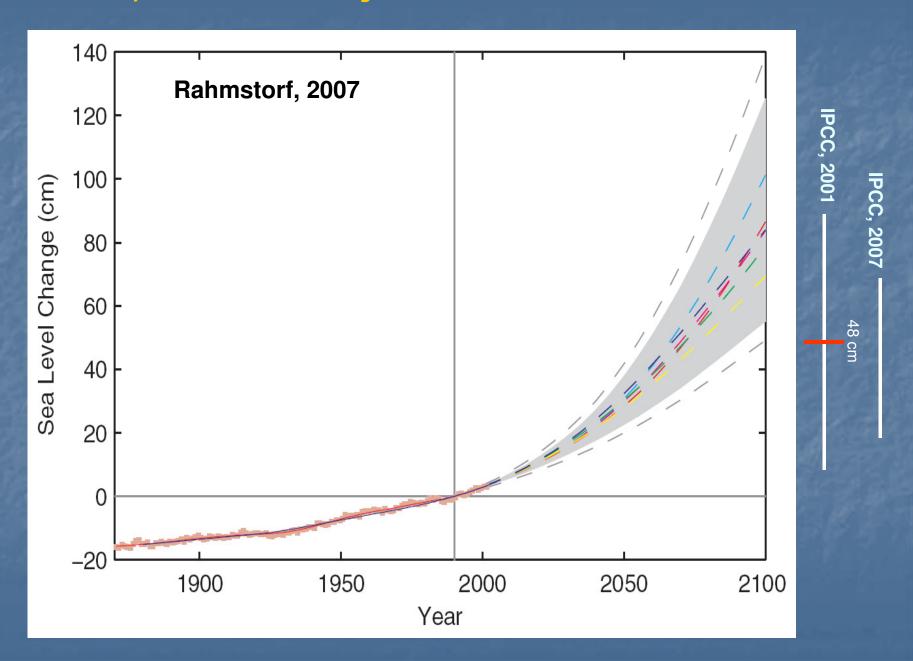
In 2005, melting accelerated dramatically yet again

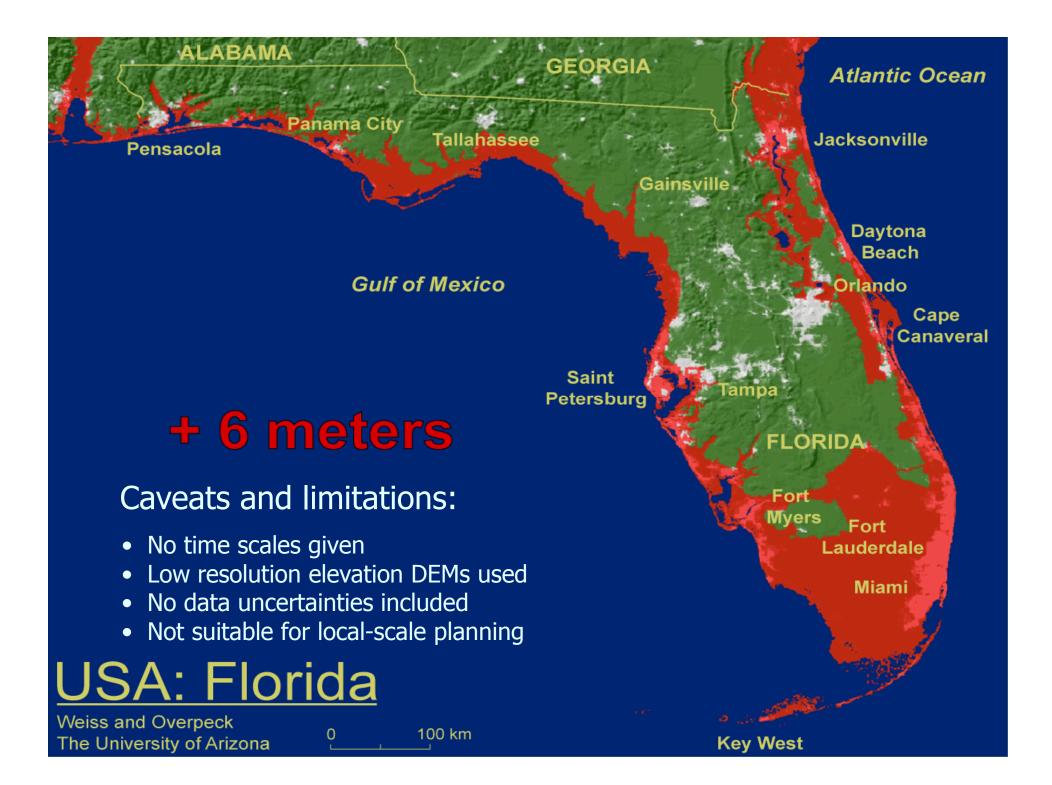
Source: ACIA, 2004 and CIRES, 2005

Effects of increased sea-level rise and storm intensity

- Loss of coastal habitats and resources
- Increased coastal erosion
- Loss of recreation resources (beaches, marshes)
- Saltwater intrusion into aquifers, water wells, septic systems
- Elevated storm-surge flooding levels
- Greater, more frequent coastal inundation
- Increased risk to people and infrastructure

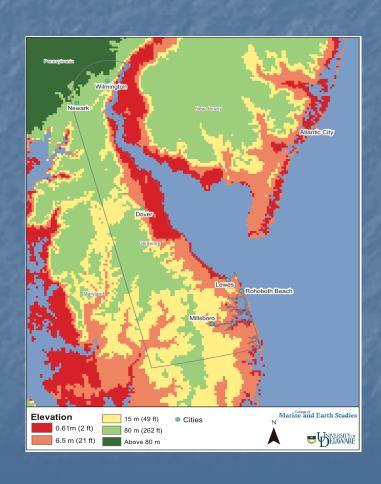
Past, Current and Projected Sea-level Rise 1875-2100

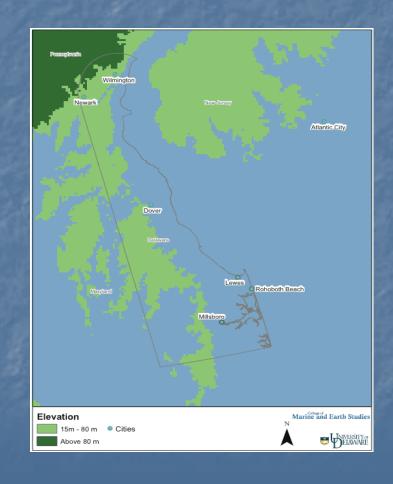




Example of inundation mapping (Un of Delaware)

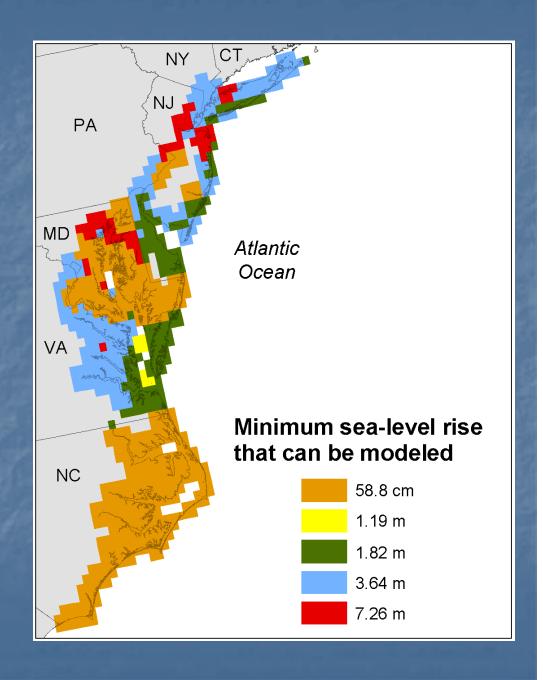
"Areas inundated by expected sea level rise in this century (red), by Greenland (orange), and by the West Antarctic (yellow). Light green are the areas inundated by additional loss of the entire Antarctic, but the probability and time constant of this are very poorly estimated."





Coastal Elevation Data

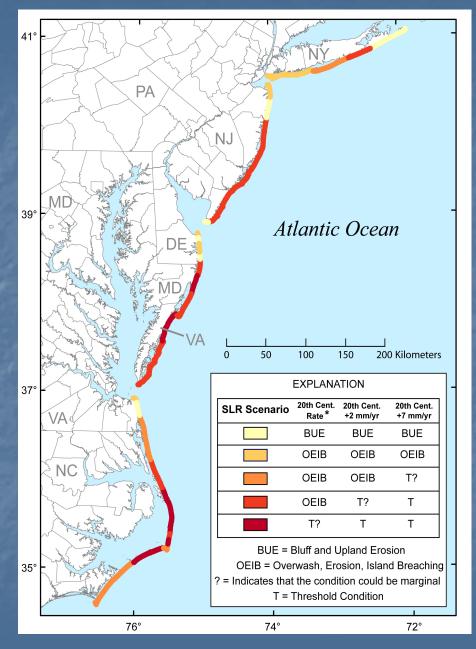
- Elevation is a critical factor in assessing potential impacts (specifically, inundation). Current elevation data do not provide the degree of confidence needed for quantitative assessments for local decision making
- Collection of high-quality elevation data (lidar) is needed



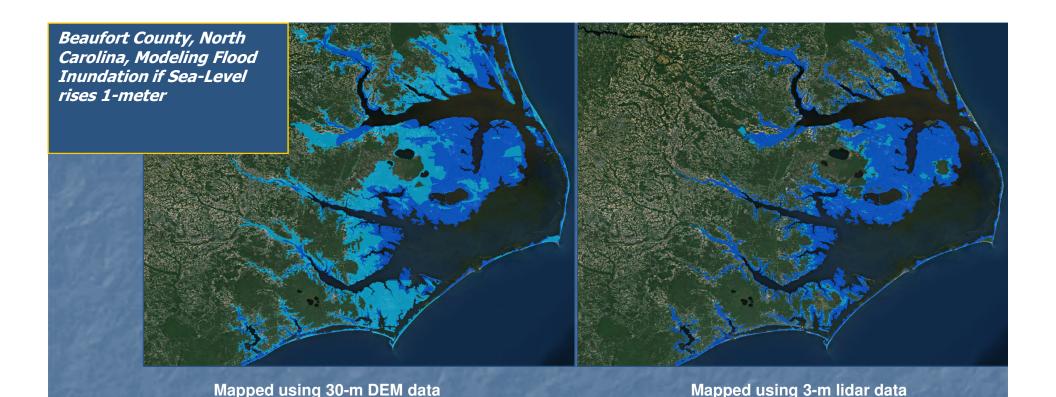
From CCSP, SAP 4.1 (2009)

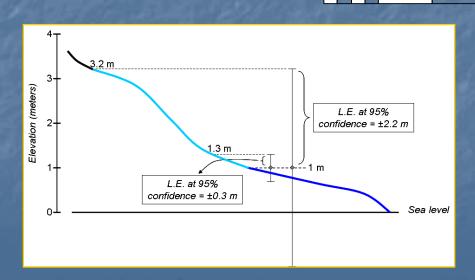
SLR Effects on Ocean Coasts

- It is virtually certain that erosion will dominate changes in shoreline position along the mid-Atlantic ocean coasts in response to sea-level rise and storms
- For higher sea-level rise scenarios, it is very likely that some portions of the mid-Atlantic coast will undergo large changes which will depend in part on local geologic and oceanographic conditions
- Specifically, some barrier island coasts will likely cross a threshold and become prone to more rapid landward migration or segmentation



From CCSP, SAP 4.1 (2009)





Dark blue Land ≤ 1 meter elevation **Light blue** Area of uncertainty

associated with 1 meter elevation

 High quality elevation data reduce uncertainty of potentially inundated areas

From CCSP, SAP 4.1 (2009)



Conclusions

- Climate systems are complex. Humans are altering global climate. Climate is becoming more variable, less predictable, warmer. Effects: sea-level rise, more storminess, more erosion, more floods and droughts. Rates of change are a concern
- Sea-level rise and storms are primary drivers of coastal change, both are increasing. Erosion and flooding will increase in magnitude and frequency
- Oceans are warming, SLR is accelerating due to thermal expansion and increased melting of glaciers and ice sheets. Future sea level is likely 0.5-1m higher by year 2100. Greenland and West Antarctica rapid melting are concerns
 - Warming ocean temps are increasing Atlantic storm intensity in addition to natural cycles of storm activity. Effects on storm frequency are still uncertain

Solutions

Mitigation and Adaptation- cut carbon release with new technologies; conservation; improve science and monitoring (Lidar, modeling); include climate science in coastal planning





U.S. Climate Change Science Program

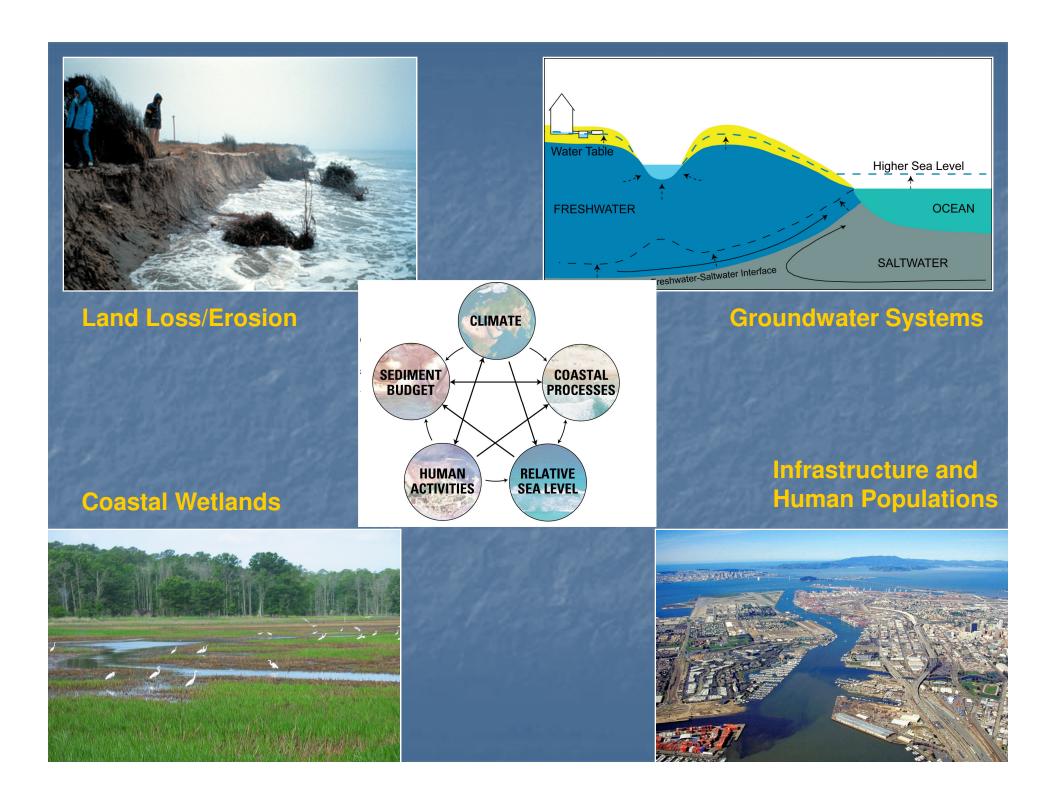
Synthesis and Assessment Product 4.1

"Coastal Elevation and Sensitivity to Sea-level Rise:
A Focus on the mid-Atlantic Region"

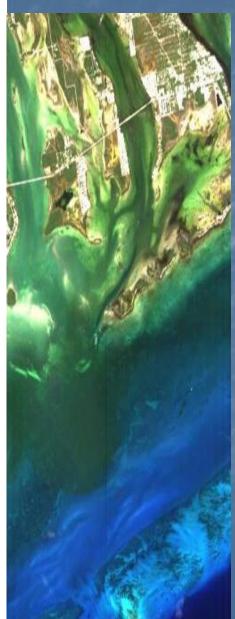
(Leads: EPA, USGS, NOAA)

Topics:

- 1. Sea-level rise, state-of-the-science, knowledge gaps
- 2. Factors that influence shoreline change
- 3. Methods of predicting future shore the change
- 4. Science plan for future research on predicting SLR effects

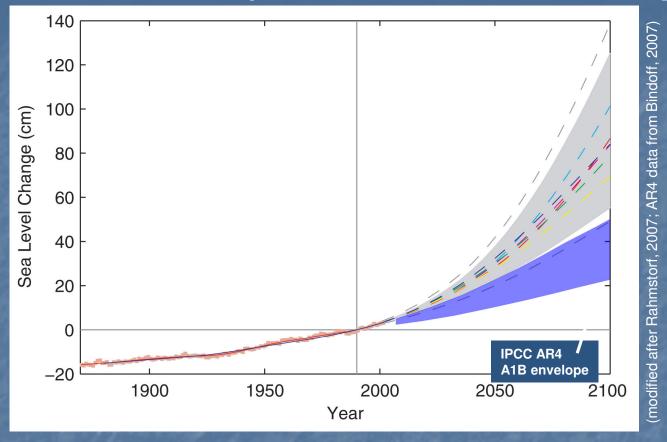


Importance of Lidar Data for Coastal Planning and Management

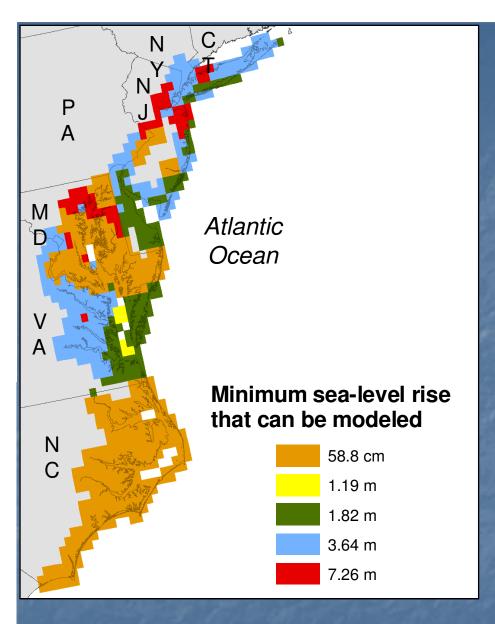


- Coastal hazards / flooding
- Coastal uplands / ecosystem management
- Hydrography
- Shoreline mapping
- Storm modeling
- Coastal Erosion
- Benthic habitats

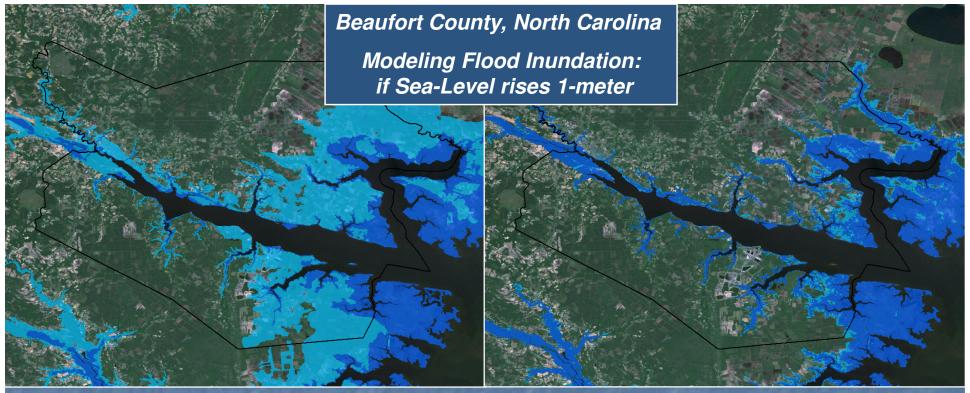
Global Sea-Level Rise Projections Will Affect U.S. Coastal Regions



- •This chart incorporates the range of peer-reviewed sea-level rise estimates to 2100
- •Sea level rise is increasing flood frequency and inundating low-lying coastal areas.
- •U.S. coastal populations have doubled over the past 50 years, greatly increasing exposure to risk from storms and rising sea level.



Current USGS NED elevation data generally not adequate for regional and national-scale inundation mapping of sea-level rise effects by the year 2100. Lidar data is needed for local mapping studies. From CCSP, SAP 4.1 (2009).



Calculated using 30-m DEM

Calculated using 3-m lidar data

Darker blue tint: Inundated land if sea level rose <1-meter

Lighter blue tint: Area of uncertain inundation if sea level rose ≤ 1-meter

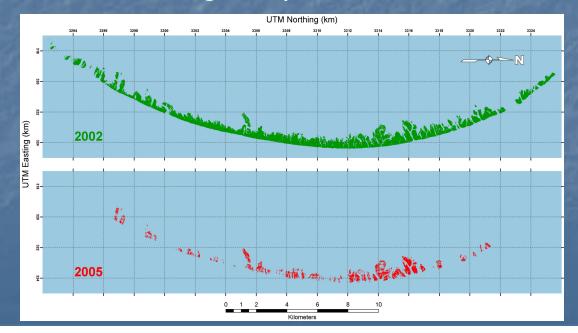
Potential Climate Change Impacts

- Temperature (local, regional, global)
- Water Cycle (precipitation/evaporation, lake and sea levels)
- Vegetation (plant cover, invasive plants, pests and pathogens)
- Fish and Wildlife (aquatic, marine, and terrestrial animals, invasive species)
- Landscape Modification--inundation, coastal erosion, storms, altered coastal processes

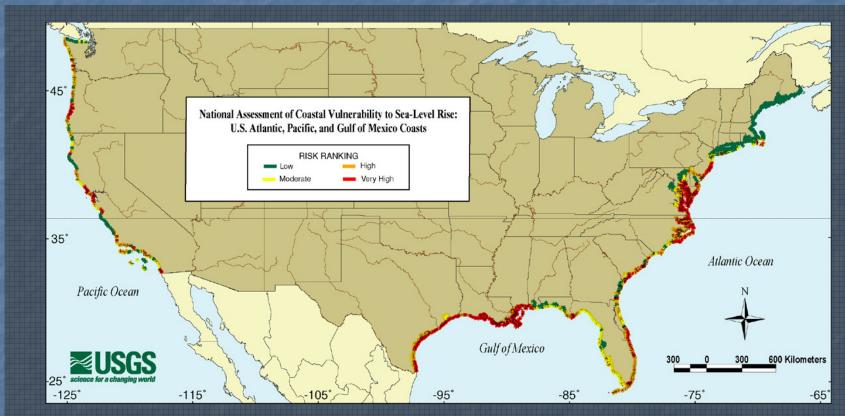
Concern about non-linear behavior, "thresholds" for stability of coastal landforms may be crossed due to SLR, storms

- Increased barrier migration, erosion on ocean and bay side, island narrowing, berm/dune lowering, breaching and island segmentation
- Consequences may be dire for U.S. barrier islands, spits, and wetlands
- Barriers are ~50% of U.S. coast; ~90% of mid-Atlantic region

Chandeleur Islands extreme coastal change... 85% land loss from Hurricane Katrina; erosion continues, modest recovery to date, effects of Hurricane Gustav being surveyed.......



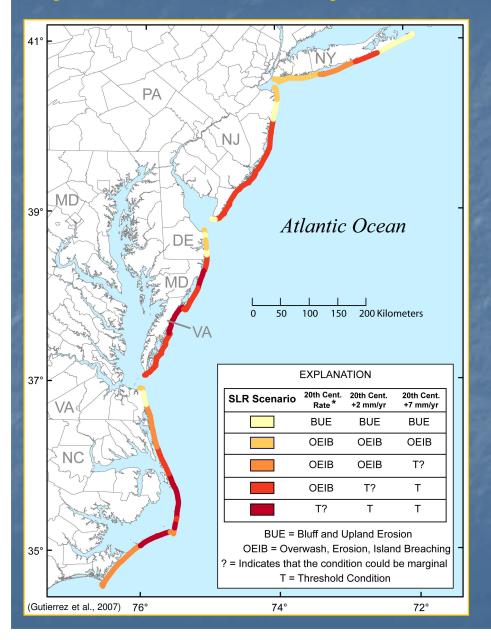
Coastal Vulnerability Index



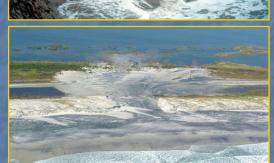
National Assessment of Coastal Vulnerability to Sea-Level Rise E. Robert Thieler, S. Jeffress Williams, Erika Hammar-Klose



Mid-Atlantic Assessment of Potential Dynamic Coastal Responses to Sea-level Rise



Bluff erosion



Overwash



Island Breaching



Threshold Crossing



Possible Responses to Coastal Erosion and Sea-level Rise

- Status quo current response to storm and erosion- a combination of armoring, nourishment, and relocation (short term, SLR not considered)
- * "Hard engineering" shoreline protection groins, breakwaters, seawalls, bulkheads, revetments, levees, dikes, jetties
- * "Soft engineering" shoreline protection beach and dune nourishment, sediment bypassing & back passing, beneficial reuse of sediment, Regional Sediment Management
- * Coastal resilience- longer term coastal zone plans, erosion setbacks, economic inducements, undevelopment, strategic relocation, open space purchases, conservation easements